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Research Article

Asymmetrical Coplanar Vivaldi Antenna Design

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Abstract

In recent years, studies about miniaturization of wideband antennas had become popular with rapid development of antenna design technologies. Vivaldi antenna is one of these antennas which can be used in different areas such as microwave imaging, antenna arrays, ground penetrating radar applications. In this paper it is intended to approach with a novel method to reduce dimensions of Vivaldi Antennas because of its advantages such as simple configuration, wide bandwidth characteristics, low profile and low cost at fabrication process. Unlike traditional forms of Vivaldi Antennas it is used asymmetrical curves in this study. These curves have a different exponential coefficient to make the antenna have an asymmetrical shape. In this study the simulation results of the designed structure and a Coplanar Vivaldi Antenna were compared and the designed antenna showed similar characteristics. To verify the results a prototype of the Asymmetrical Vivaldi Antenna was fabricated on FR4 substrate with 4.6 dielectric constant. Measurement results illustrated that return loss of the designed antenna is below -10dB between 0.177GHz and 2.74GHz frequencies and the antenna have 93% fractional bandwidth. The measurement results match simulation results. Wideband frequency range, simple configuration and reduced dimensions make the designed antenna a good candidate for wideband antenna applications in future.

Keywords: Asymmetrical Coplanar Vivaldi Antenna, Wideband Antenna, Tapered Slot Antenna, UWB, Miniaturization.

Asimetrik Eşdüzlemsel Vivaldi Anten Tasarımı

Son yıllarda anten tasarım teknolojilerinin hızla gelişmesiyle geniş bant antenlerin minyatürleştirilmesi çalışmaları popülerlik kazanmıştır. Bu tür antenlerden biri olan Vivaldi Antenler mikrodalga görüntüleme, anten dizileri, yere nüfuz eden radar uygulamaları gibi alanlarda kullanılabilmektedir. Bu yazıda; basit konfigürasyon, yüksek bant genişliği özellikleri, düşük profil ve üretim sürecinde düşük maliyet gibi avantajları nedeniyle Vivaldi Antenlere boyutları küçültmek için yeni bir yöntemle yaklaşım amaçlanmıştır. Bu çalışmada Geleneksel Vivaldi Anten türlerinin aksine asimetrik eğriler kullanılmıştır. Bu eğrilerde antenin asimetrik şeklini sağlamak için farklı exponansiyel katsayılar vardır. Çalışmada tasarlanan yapı ile Eşdüzlemsel Vivaldi Antenin simülasyon sonuçları karşılaştırılmış ve tasarlanan anten benzer sonuçlar göstermiştir. Sonuçları doğrulamak için Asimetrik Vivaldi Antenin bir prototipi 4.6 dielektrik sabiti olan bir FR4 taban malzemesi üzerine üretilmiştir. Ölçüm sonuçları tasarlanan antenin 0.177GHz ve 2.74GHz frekansları arasında geri dönüş kaybının -10dB'in altında olduğunu göstermektedir ve anten %93 bant genişliğine sahiptir. Geniş frekans aralığı, basit konfigürasyon ve azaltılmış boyutlar tasarlanan anteni gelecekte genişbant anten çalışmaları için iyi bir aday yapmaktadır.

Anahtar Kelimeler: Asimetrik Eşdüzlemsel Vivaldi Antenna, Genişbant Anten, Açıklığı Daralan Anten, Ultra Geniş Bant, Minyatürleştirme.

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1. Introduction

In recent years, studies miniaturization of wideband antennas had become popular with rapid development of antenna design technologies. Researchers paid a great attention studies about miniaturization of antennas(Pan et al, 2021; Hu et al, 2019; Geng et al, 2017; Liu et al, 2016). Vivaldi antennas seems to be most appropriate candidate for these studies because of its simple configuration, wide bandwidth characteristics, low profile and low cost(Du et al, 2019).

Vivaldi antenna was first introduced in 1979 by Gibson(Gibson,P.J., 1979). The Vivaldi antenna, also known as tapered slot antenna (TSA). This antenna has an exponential aperture in order to provide a large operating bandwidth. Vivaldi Antennas can be used in different areas such as microwave imaging, antenna arrays, ground penetrating radar applications etc(Yue et al, 2016; Reid et al, 2012; Warathe et al, 2019).

2. Material and Method

2.1. Coplanar Vivaldi Antenna Design

This paper aims to provide a new approach on Vivaldi Antennas to reduce dimensions. In this study, it is focused on Coplanar Vivaldi Antennas.

Dielectric substrate that has chosen for this study is FR-4 because of its cost-effective feature(Tahar et al, 2018). Dielectric constant of the substrate is 4. 6 and loss tangent is 0.016. Height of the substrate h is 1.6 mm, thickness of patch copper at bottom and top sides t is 0.035 mm.

Mathematical equations of a traditional Coplanar Vivaldi Antenna can be shown as below:

$$y(x) = \pm Ae^{RX} \quad (1)$$

Equation (1) shows the function of exponential curves on the Vivaldi antenna. Here R parameter shows opening rate and A is a constant. The evolution of A and R parameter are given at equation (2) and (3).

$$A = \frac{S}{2} \quad (2)$$

$$R = \frac{1}{La}\ln\left(\frac{Wa}{S}\right) \quad (3)$$

Length of two exponential curves is denoted by La and opening width between two exponential curve endings is denoted by Wa. The parameter S shows throat width at the origin.

$$Wa = \frac{c}{2\sqrt{\mathrm{Er}}(fl)} \quad (4)$$

$$S = \frac{c}{2\sqrt{\mathrm{Er}}(fh)} \quad (5)$$

In order to calculate parameters Wa and S, equations (4) and (5) are used. In equation (4) and (5) c is the velocity of light and Er is the dielectric constant of the substrate. Parameter fl shows lower operating frequency and parameter fh shows higher operating frequency of the antenna. These are parameters that used in designing of Coplanar Vivaldi Antenna(Thalluri et al, 2020).

Table 1. Dimensions of Coplanar Vivaldi Antenna

Parameter	Dimension	Parameter	Dimension
W	750 mm	BL	10 mm
L	500 mm	Wa	405.64 mm
Rs	25 mm	wm1	3 mm
Rc	18 mm	wm2	2.5 mm
S	1.5 mm	**θ**	90°

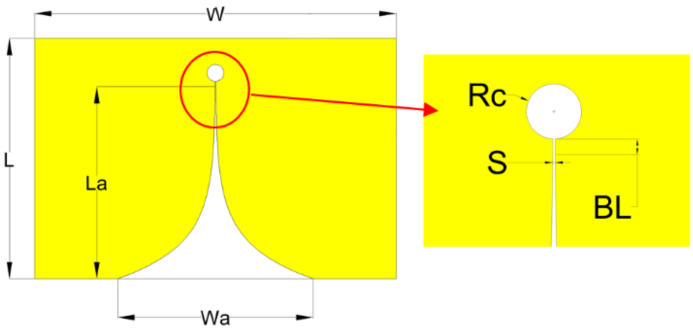

Fig 1. Bottom view of Coplanar Vivaldi Antenna

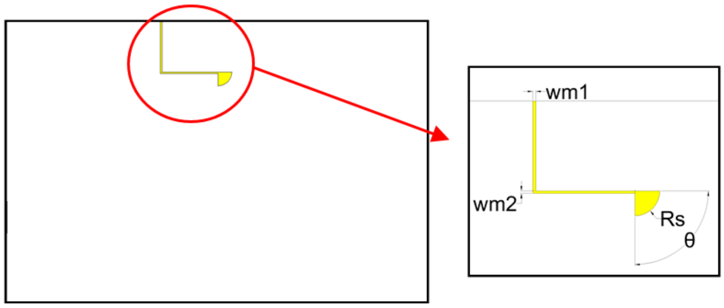

Fig 2. Top view of Coplanar Vivaldi Antenna

Configuration of the Coplanar Vivaldi Antenna dimensions are given in Table 1. Bottom and top view of the antenna are illustrated in Fig.1 and Fig.2. The antenna fed by a microstrip line with 50Ω characteristic impedance.

2.2. Coplanar Vivaldi Antenna Design

Traditional Coplanar Vivaldi Antenna requires larger volume due to the relation between lower frequency and opening width of two exponential curve endings. In this study it is aimed to reduce dimensions of the Vivaldi Antenna in order to integrate this antenna to the new systems. Also reducing the dimensions will be useful for antenna arrays.

By using equation (6) and (7) exponential curves become asymmetrical if different values are chosen for parameter P and R. These two exponential curves provide a new parameter for optimization. Fig. 3 shows change of exponential curves with parameter. Fig. 4 and Fig. 5 illustrates the bottom and top view of the Asymmetrical Coplanar Antenna. The dimensions of final setup are shown in Table II.

$$y1(x) = Ae^{PX} \quad (6)$$

$$y2(x) = Ae^{RX} \quad (7)$$

Table 2. Dimensions of Asymetrical Vivaldi Antenna

Parameter	Dimensions	Parameter	Dimensions
W	447 mm	Θ	94.6 °
L	283 mm	wm1	3 mm
Rs	23.3 mm	wm2	2.4 mm
Rc	13.9 mm	W1	187.56 mm
BL	38.42 mm	L1	262.02 mm
S	1.54 mm		

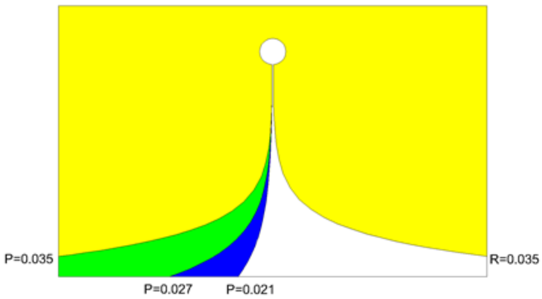

Fig 3. View of Asymmetrical Curves

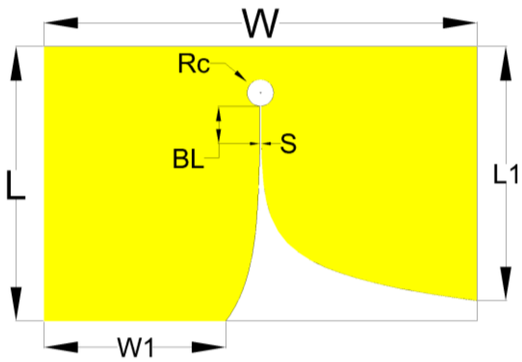

Fig 4. Bottom view of Asymmetrical Vivaldi Antenna

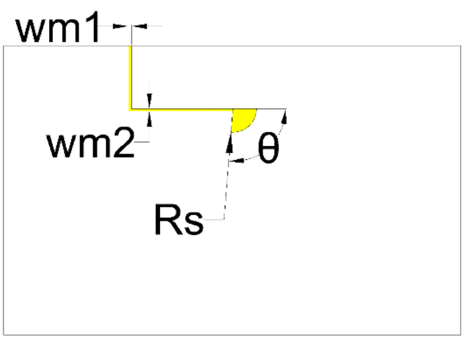

Fig 5. Top view of Asymmetrical Vivaldi Antenna

3. Results and Discussion

3.1. Return Loss, Gain and Radiation Pattern

Traditional Coplanar Vivaldi Antenna and Asymmetrical Vivaldi Antenna were simulated in CST Studio Software. Fig. 6. shows change of return loss of the Asymmetrical Vivaldi Antenna according to parameter P. Fig. 7. illustrates the comparison of return loss.

Return loss(S11) of the proposed antenna is below -10dB between 0.18 GHz and 2.71GHz. And return loss of traditional Coplanar Vivaldi Antenna is smaller than -10dB between 0.18GHz and 2.86GHz.

Gain characteristics of two antennas are shown in Fig. 8. The gain values of the proposed antenna are near to the values of traditional Coplanar Vivaldi Antenna.

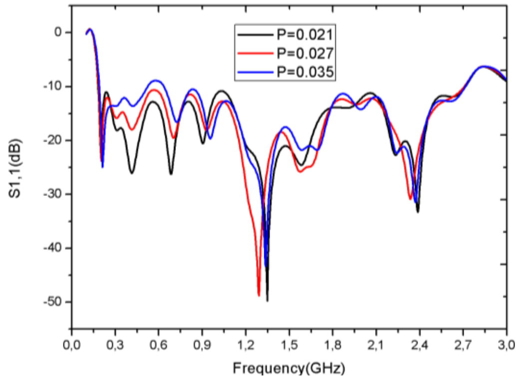

Fig 6. Return Loss(S1,1) for different values of P

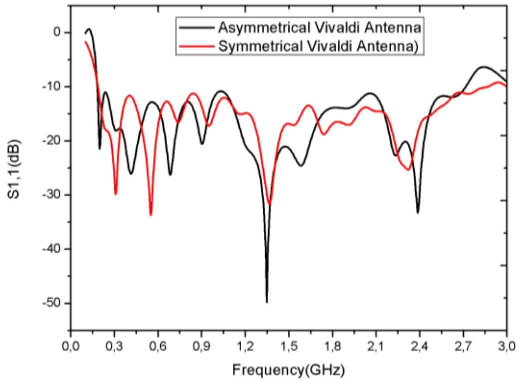

Fig 7. Return Loss(S1,1) of two antennas

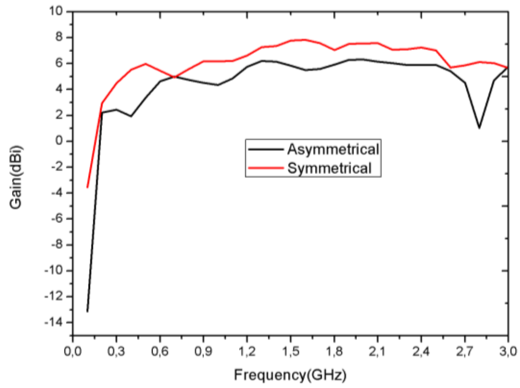

Fig 8. Gain(dBi) of two antennas

Radiation pattern of two antennas for different frequencies is presented in Fig. 9. It is clear that asymmetrical curves shift radiation pattern of the proposed antenna. Even though the gain decreases in the proposed antenna general characteristics are near to the values of traditional Coplanar Vivaldi Antenna. Asymmetrical Vivaldi Antenna has different characteristics in different frequencies because of the exponential curves. Normally increasing opening rate of exponential curves provides a larger bandwidth for traditional Vivaldi Antennas. The proposed antenna have two different opening rates for upper and bottom curves. That's why this structure changes directivity of the antenna and provides a better bandwidth.

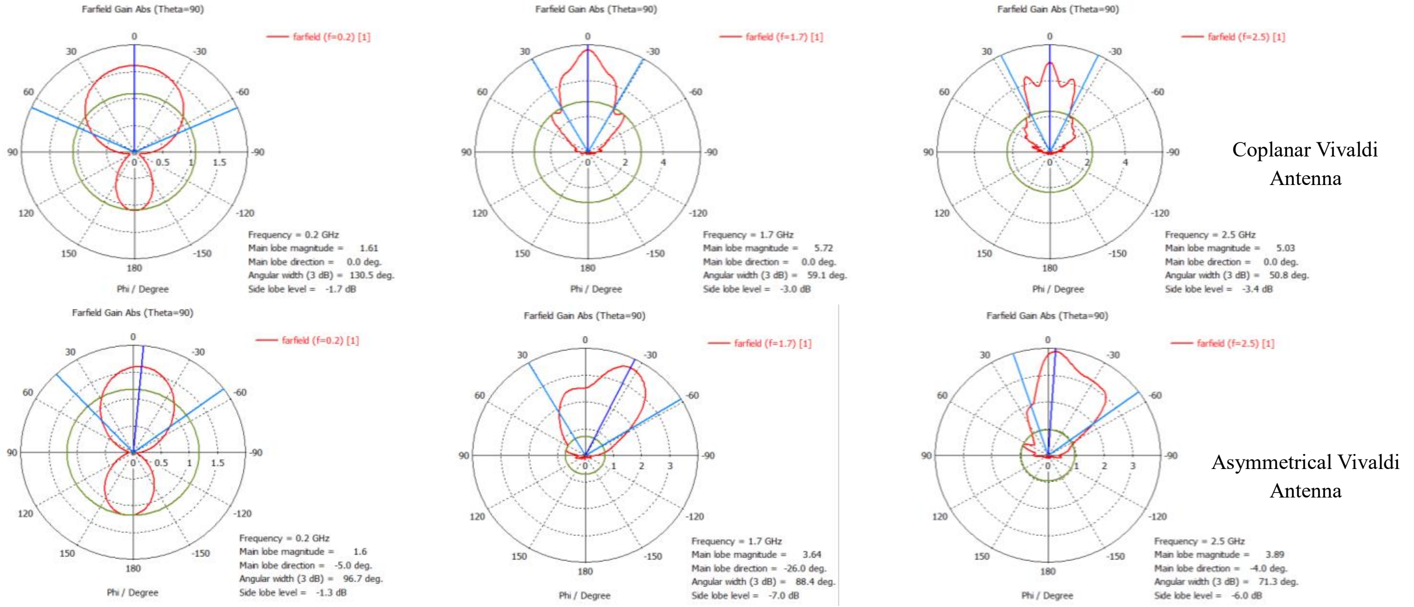

Fig 9. Radiation pattern of two antennas

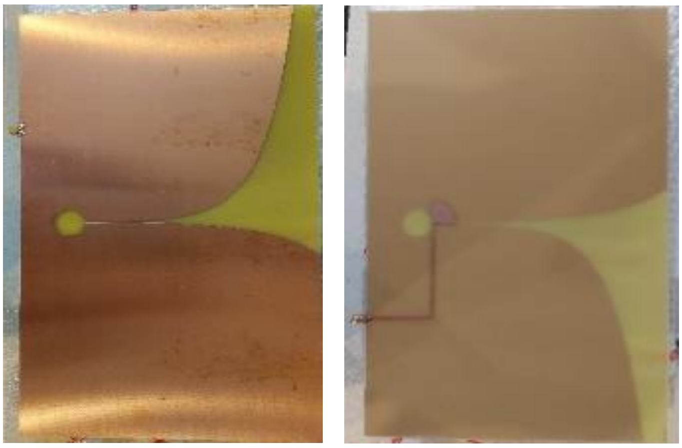

Fig 100. Bottom and Top View of Fabricated Antenna

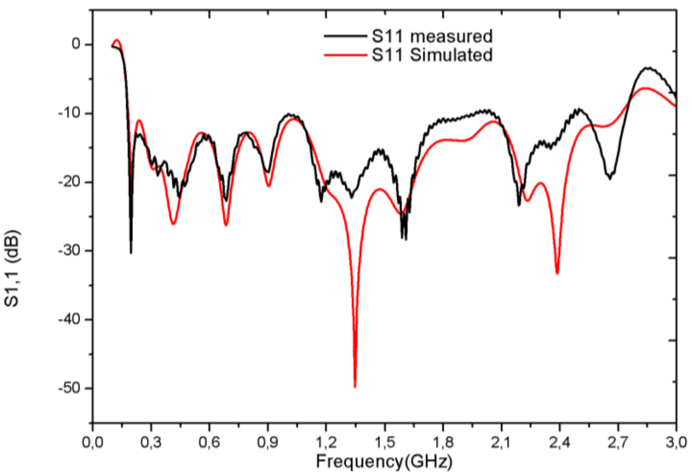

Fig 11. Return Loss(S1,1) of Fabricated Antenna

3.2. Fabrication and Measurement

To validate the performance of the Asymmetrical Coplanar Vivaldi Antenna, a prototype of this antenna was fabricated in dimension given in Table 2. Bottom and top view of the fabricated antenna are shown in Fig. 10.

SMA connector was soldered to provide excitation to the antenna and then the antenna was tested using MS4646A Vector Network Analyzer (VNA). Antenna placed 3m distance from VNA. The comparison results are shown in Fig. 11.

In this study it is seen that asymmetrical exponentials provided 33% smaller area for this frequency range when compared with traditional Coplanar Vivaldi antenna. The designed antenna also provides a size and cost effective structure when compared antennas that work in similar frequencies, in literature given at Table 3.

As an example, the antenna at paper (Elsheakh & Abdallah, 2019) has a less electrical size but less bandwidth when compared ith the antenna at this study. Even though both antennas have substrate materials with similar dielectric coefficients, the antenna at this study is in advantageous position in terms of bandwidth. Also the designed antenna has an advantage in terms of electrical size and bandwidth against the antenna at paper (Huang et al., 2021).

At paper (Honari et al., 2021), using low dielectric coefficient substrate and large electrical size have made the bandwidth larger than the antenna at this study. Considering that the bandwidth decreases as the dielectric coefficient increases, it can be interpreted that the antenna in this study will be more advantageous in terms of bandwidth when produced with materials with the same dielectric coefficient of the antenna at paper (Honari et al., 2021).

4. Conclusions and Recommendations

In this paper it is shown a new approach for Vivaldi Antenna designs. Asymmetrical Coplanar Vivaldi Antenna can work between 0.177GHz and 2.74GHz frequencies according to measurement results. It is quite similar with simulation results. Deviation on return loss of the fabricated antenna are because of non-ideal material characteristics and noise.

It is clear that using asymmetrical curves for Vivaldi Antenna designs can help us to miniaturize antennas. Moreover a reduced antenna size might be an attractive research area for future studies of Vivaldi Antennas.

Table 3. Comparison of Vivaldi Antennas

Reference	Dielectric constant	Antenna Size (L x W x h)	Operating Frequency (GHz)	Bandwidth (%)
(Honari et al., 2021)	2.55	0.3 λ × 0.38 λ	0.72 – 17	183,74
(Huang et al., 2021)	4.4	0.68 λ × 0.59 λ	0.8 - 6	152,94
(Cheng et al., 2020)	4.3	0.7 λ × 0.65 λ	0.7 - 2.1	100
(J. Guo, et al., 2019)	3.38	0.6 λ × 0.45 λ	0.3 - 2	147,82
(M. Guo, et al., 2019)	3.38	0.76 λ × 0.481 λ	0.95 - 11	91,36
(Elsheakh & Abdallah, 2019)	4.4	0.17 λ × 0.16 λ	0.4 - 10	96
This study	4.6	0.16 λ × 0.26 λ	0.177-2.74	93
Note: λ represent wavelength at min. working frequency.				

5. Acknowledge

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